

WHAT IS CLAIMED IS:

1. An audio system for use in a vehicle having a roof, the system comprising:

5 a headliner adapted to be mounted adjacent the roof so as to underlie the roof and shield the roof from view, the headliner having an upper surface and a sound-radiating, lower surface;

a source of audio signals;

10 an array of electromagnetic transducer assemblies supported at the upper surface of the headliner;

15 signal processing circuitry coupled to the assemblies for processing the audio signals to obtain processed audio signals wherein the assemblies convert the processed audio signals into mechanical motion of corresponding zones of the headliner and wherein the headliner is made of a material which is sufficiently stiff and low in density so that the headliner radiates acoustic power into the interior of the vehicle with a frequency range defined by a lower limit of 100 hertz or less and an upper limit of 12 kilohertz or more and the processed audio signals at a low end of the frequency range are matched to the processed audio signals at mid and high ends of the frequency range.

20 2. The system as claimed in claim 1 wherein the vehicle has a windshield and wherein the array of electromagnetic transducer assemblies includes at least one row of electromagnetic transducer assemblies adjacent the windshield and wherein the at least one row of electromagnetic transducer assemblies are positioned 5 to 30 inches in front of an expected position of a passenger in the interior of the vehicle.

25 3. The system as claimed in claim 2 wherein the at least one row of electromagnetic transducer assemblies are positioned 12 to 24 inches in front of the expected position of the passenger.

4. The system as claimed in claim 2 wherein the at least one row of electromagnetic transducer assemblies includes at least two electromagnetic

transducer assemblies spaced apart to correspond to left and right ears of the passenger in the expected position of the passenger.

5 5. The system as claimed in claim 1 wherein each of the electromagnetic transducer assemblies includes a magnet for establishing a magnetic field in a gap formed within the assembly, a coil which moves relative to the magnet in response to the processed audio signals, a base fixedly secured to the headliner on the upper surface and electrically connected to the signal processing circuitry and a guide member electrically connected to the coil and removably secured to the base for supporting the coil in the gap and wherein the coils are electrically coupled to the signal processing circuit when the guide members are secured to their corresponding bases.

10 6. The system as claimed in claim 5 wherein each of the magnets is a high-energy permanent magnet.

15 7. The system as claimed in claim 6 wherein each of the high-energy permanent magnets is a rare-earth magnet.

20 8. The system as claimed in claim 5 wherein each of the assemblies includes a spring element having a resonant frequency below the lower limit of the frequency range when incorporated within its assembly and connected to its corresponding guide member for resiliently supporting its corresponding magnet above the upper surface of the headliner.

25 9. The system as claimed in claim 1 wherein the array of electromagnetic transducer assemblies includes a front row of electromagnetic transducer assemblies positioned 5 to 30 inches in front of an expected position of a passenger in the interior of the vehicle and a back row of electromagnetic transducer assemblies positioned behind the expected position of the passenger wherein the signal processing circuitry delays the audio signals coupled to the back row of electromagnetic transducer assemblies relative to the audio signals coupled to the front row of electromagnetic transducer assemblies.

10. The system as claimed in claim 1 wherein the array of electromagnetic transducer assemblies are completely supported on the upper surface of the headliner.

5 11. The system as claimed in claim 1 further comprising at least one loudspeaker coupled to the signal processing circuitry, and adapted to be placed in the interior of the vehicle in front of an expected position of a passenger and below the headliner.

10 12. The system as claimed in claim 1 wherein the headliner material has a flexural modulus between 1E7PA and 4E9PA and a density of between 100 and 800 kg/m³.

13. The system as claimed in claim 1 wherein the electromagnetic transducer assemblies are spaced to the left and right, front and rear of expected positions of passengers in the interior of the vehicle to create proper audio imaging for the passengers.

15 14. The system as claimed in claim 1 further comprising at least one loudspeaker positioned in front of expected positions of passengers below the headliner but not in doors, kick panels, or under a dash of the vehicle.

15. The system as claimed in claim 1 further comprising a low frequency speaker positioned below the headliner in the interior of the vehicle.

20 16. The system as claimed in claim 1 wherein the array has front and rear assemblies and wherein each rear electromagnetic transducer assembly is coupled to processed audio signals delayed in time relative to the processed audio signals coupled to each front electromagnetic transducer assembly.

25 17. The system as claimed in claim 1 wherein the audio signals are processed with head-related transfer functions by the signal processing circuitry.

18. The system as claimed in claim 1 wherein the electromagnetic transducer assemblies are supported only on the headliner.

19. The system as claimed in claim 1 wherein the headliner is self-supporting.

20. The system as claimed in claim 1 further comprising a semi-compliant attachment mechanism adapted to attach the headliner to the roof along at least a substantial periphery of the roof.

21. The system as claimed in claim 1 further comprising a semi-compliant attachment mechanism adapted to attach the headliner to the roof along at least a substantial periphery of the roof and a central portion of the roof.

22. The system as claimed in claim 1 further comprising a support structure for reinforcing the headliner.

23. The system as claimed in claim 1 further comprising framing independent of the headliner to support the assemblies.

24. The system as claimed in claim 1 wherein the headliner material has a flexural modulus between 1E7PA and 4E9PA and a density between 100 and 800 kg/m³ and wherein the headliner material may be made from a single material or composites.

25. The system as claimed in claim 1 wherein stiffness and density of the headliner material is altered around the entire periphery of the headliner to allow for additional excursion of the entire headliner in order to create better low frequency reproduction (< 200 Hz) of the processed audio signals.

26. The system as claimed in claim 1 further comprising a fabric or other material adhered to the lower surface of the headliner to create a cosmetically acceptable appearance for the system.

5 27. The system as claimed in claim 1 further comprising a fabric or other material adhered to the upper surface of the headliner for routing wires over the headliner in order to keep the wires from vibrating when in contact with a vibrating headliner.

28. The system as claimed in claim 1 further comprising audio signal wires integrated into the headliner.

10 29. The system as claimed in claim 1 further comprising a material adhered to the headliner to provide additional mass or damping or stiffness thereby minimizing unwanted excess vibration caused by any resonances in the headliner material.

15 30. The system as claimed in claim 1 further comprising fiberglass or other suitable material positioned between the headliner and the roof to minimize undesirable acoustical reflections from the roof, to minimize standing waves set up in a cavity created between the headliner and the roof and to prevent the array of electromagnetic transducer assemblies from engaging the roof.

20 31. The system as claimed in claim 1 wherein a electromagnetic transducer assembly for a local sound zone is located between 5" and 30" in front of an expected ear location for a passenger.

32. The system as claimed in claim 1 wherein at least one of the electromagnetic transducer assemblies is adhered directly to the headliner.

25 33. The system as claimed in claim 1 wherein each of the electromagnetic transducer assemblies includes a subassembly having vibrational characteristics and adapted to be screwed, snapped, or twisted into position at the

upper surface of the headliner whereby vibrational characteristics of each of the subassemblies can be tested for performance and quality prior to its installation on the headliner.

5 34. The system as claimed in claim 33 wherein each of the assemblies includes a base fixedly secured to the headliner and a bayonet-style coupling for removably securing its corresponding subassembly to its base and wherein each coupling also makes electrical contact between a conductor which is coupled to the circuitry and its corresponding subassembly.

10 35. The system as claimed in claim 1 wherein the processed audio signals to be delivered to each electromagnetic transducer assembly may be routed to alternate electromagnetic transducer assemblies to achieve different imaging and performance goals, the processed audio signals being monaural, stereo, or multi-channel signals.

15 36. The system as claimed in claim 1 wherein an acoustical center channel signal in a multi-channel setup is achieved by sending a processed center channel signal to both left and the right channel electromagnetic transducer assemblies in a row of electromagnetic transducer assemblies and utilizing mechanical mixing of the headliner to move the headliner between the left and right channel electromagnetic transducer assemblies as a center channel speaker.

20 37. The system as claimed in claim 1 further comprising a compliant material positioned between the assemblies and the roof.

38. The system as claimed in claim 1 further comprising at least one microphone positioned in the interior of the vehicle for intra-cabin and extra-cabin communications (cellular, digital, etc).

25 39. The system as claimed in claim 1 wherein the processed audio signals represent global or local vehicle warnings delivered to the entire or local interior sections of the vehicle.

40. The system as claimed in claim 1 wherein the signal processing circuitry utilizes adaptive filtering techniques to perform automatic system equalization.

41. The system as claimed in claim 1 wherein each area in the interior of the vehicle can be separately equalized.

42. The system as claimed in claim 1 wherein the headliner has a relatively high coincidence frequency to maximize channel separation, provide accurate imaging and minimize distortion and wherein the coincidence frequency is greater than 12 KHz.

43. The system as claimed in claim 1 wherein the audio signals are processed with trans-aural techniques to widen or narrow an image.

44. The system as claimed in claim 1 wherein the headliner has a structure which is broken at a flexure to minimize transfer of mechanical motion across the flexure.

45. The system as claimed in claim 1 wherein the system has a frequency response shape wherein the signal processing circuitry changes the shape of an equalization curve applied to the audio signals based on the signal level of the audio signals to maintain the frequency response shape relatively constant as the signal level of the audio signals change.

46. An electromagnetic transducer assembly comprising:
a subassembly including:
a housing;
a magnet for establishing a magnetic field within the housing;
a coil which moves relative to the magnet in response to an
audio signal; and

a flexible spider and guide member for supporting the coil centrally within the magnetic field; and

a mating base for attaching the subassembly to a vehicle headliner wherein the subassembly is removably secured to the mating base by screwing, snapping or twisting.

47. The assembly as claimed in claim 46 wherein the flexible spider includes a plurality of flexing legs circumferentially spaced about an outer periphery of the spider.

48. The assembly as claimed in claim 47 wherein each of the flexing legs has a shape of a sinusoidal wave.

49. The assembly as claimed in claim 47 wherein each of the flexing legs has a pair of end portions which taper to a relatively thin middle portion.

50. The assembly as claimed in claim 49 wherein each of the flexing legs has at least one edge profile which follows a cosine function.

51. The assembly as claimed in claim 46 further comprising a bayonet-style coupling for mechanically connecting the spider and guide member to the base and electrically connecting the coil to a cable which supplies the audio signal after rotation of the spider and guide member relative to the base under a biasing force.

52. The assembly as claimed in claim 51 wherein the bayonet-style coupling includes an electrically conductive spring electrically connected to the coil and supported on the spider and guide member for supplying the biasing force and electrically connecting the coil to the cable.

53. The assembly as claimed in claim 46 further comprising at least one electrically conductive member disposed between the flexible spider and guide member and the mating base for electrically coupling the coil to a flat flexible

cable disposed between the spider and guide member and the mating base upon securing the subassembly to the mating base.

54. The assembly as claimed in claim 53 wherein the at least one electrically conductive member includes a pair of spaced electrically conductive springs which urge the spider and guide member away from the mating base during securing of the subassembly to the mating base.

55. The assembly as claimed in claim 46 wherein the spider and guide member form a single part.

56. The assembly as claimed in claim 46 wherein the coil includes a notch for aligning the coil on the spider and guide member to insure proper polarity of the coil.

57. The assembly as claimed in claim 46 wherein the spider and guide member has threads for securing the spider and guide member to the housing.

58. The assembly as claimed in claim 57 further comprising an adhesive for adhesively securing the housing to the spider and guide member at the threads.

59. The assembly as claimed in claim 46 wherein the spider and guide member includes a centering ledge portion for centering the housing on the spider and guide member.

60. The assembly as claimed in claim 46 wherein the coil includes at least one conductive pin for coupling the coil to audio signals.

61. A computer system for controlling a digital signal processor which processes an audio signal of an audio system, the computer system comprising:

a computer adapted to be coupled to the digital signal processor;

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a display coupled to the computer for displaying a graph of signal delay versus signal gain of an audio signal to be manipulated by the digital signal processor; and

- 5 an input device coupled to the computer for generating an input signal, the computer being programmed with a graphic software control to modify the graph in response to the input signal wherein level and delay of the audio signal are changed simultaneously.

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